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TROMBE WALLS AND DIRECT GAIN: PATTERNS OF NATIONWIDE APPLICABILITY*

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ABSTRACT

The economic performance of Trombe wall and direct gain passive solar heating designs are evaluated on a nationwide basis using the LASL/UNM solar economic performance code. Both designs are integrated into a ranch style tract home concept thereby facilitating regional comparisons. Solar add-on costs are established for each design with regional differences in material and labor prices accounted for at each site. System sizes are optimized against the natural gas and electric resistance heating alternatives, the current price and future escalation of which is established for each locale. Results for each passive solar design are summarized on a state-by-state basis followed by a discussion of their comparative economic performance. General conclusions from the comparative analysis are drawn about the appropriateness of each design in each region.

1. INTRODUCTION

Interest in passive solar design has grown dramatically over the past several years. With this growing interest comes the need for a continued evaluation of passive-solar economic performance as new and/or updated cost and thermal performance data becomes available. In this paper the economic performance of two such designs--Trombe wall and direct gain--is assessed against the backdrop of regional energy prices and differing solar costs. A representative site from each state has been selected for the purposes of comparative evaluation. Such an approach has limitations due to the possibility of divergent conditions within any state; however, general patterns of applicability and economic performance can be identified which is useful for overall comparative analysis.

In the section below we review briefly the methodology used. This includes a discussion of architectural design criteria, solar add-on costs, thermal performance estimates, conventional energy prices and futures, and the sizing optimization procedure. The methodology section is followed by a discussion of results summarized in tables. For a more thorough discussion of the detailed methodology and additional background information, one should refer to the specific references listed throughout the paper.

2. METHODOLOGY

Five basic steps are employed in the macro (nationwide) evaluation of solar economic performance. These are (1) the specifications of architectural design parameters and passive revisions to a conventional tract home, (2) the specification of the annual thermal performance of the passive designs using simplified methods developed by the LASL Q-11 Solar Group, (3) the estimation of passive solar add-on costs which then are coupled with performance estimates to calculate costs of alternatively sized passive solar heating designs, (4) the specification of conventional energy prices and futures by locale, and (5) the determination of the economic competitiveness of the various designs based upon life cycle cost and cash flow analysis methods using the LASL/UNM solar economic performance code.

2.1 Design

A standard tract home design of approximately 1500 ft^2 is altered to accommodate the double glazed Trobe wall and direct gain designs (1,2). The home is assumed to be situated on a relatively standard sized single family residential city lot (70 X 110 ft.) and to be oriented due south for maximum possible glazing area exposure. Because we wish to compare both passive designs on a fairly equal basis, the ratio of glazing (collector) area to storage mass volume is kept constant in the design specification and thermal performance estimates. For both designs that ratio is such that for every ft^2 of glazing there is 1 ft^2 of 18 in. thick storage (1.5 ft^3), or 2 ft^2 of 9 in. thick storage (1.5 ft^3), or 3 ft^2 of 6 in. thick storage (1.5 ft^3), and so forth. In the Trombe wall design, glazing area always equals mass surface area so an 18 in. thick wall is assumed (3,4,5). For the direct gain design we look at two options. First, for the 8 ft. high south wall glazing the mass is comprised of a 6 in. slab 15 ft. deep, which abuts to an 8 ft., 8 in. thick interior mass wall. Second, 4 ft. high clerestory windows are

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used which collect solar energy to be stored in an 3 ft. high, 3 in. grouted CMU vertical north mass wall veneered to conventional frame wall construction. Both configurations allow for a glazing/mass relationship consistent with the 18 in. Trombe wall.

2.2 Performance

Results from modified solar-load ratio correlation procedures calculated by the LASL Q-11 Solar Group (5,7,3) are used to estimate the solar performance (9) of each passive design. For each solar fraction from 5 to 95 percent, a calculated LOAD/AREA (Btu/DD/ft^2) ratio from the simplified performance tables is divided into LOAD (Btu/DD defined for all surfaces other than the south wall) to give us AREA (ft^2) requirements for each desired level of solar fraction by location. With and without R-9 night insulation cases are examined for each of the passive designs.

2.3 Costs

Solar add-on costs are isolated from the usual tract home building costs for both Trombe wall and direct gain designs. The Trombe wall costs have been discussed in detail previously (1,3,5,10) and only are summarized below. A detailed breakdown of costs used for the direct gain design is contained in Table I. Note, there are two basic options--south facing windows and/or clerestory windows--which may be used together or individually in a specific design. In the economic performance evaluation all three possibilities are considered. No wall credit is given to the clerestory design(11) because it was found to be more cost effective to place the storage wall as a veneer immediately in front of the framed exterior wall than to make the storage wall load bearing with interspersed windows.

To examine sensitivities, three sets of costs are used for the Trombe wall design. National average unit costs for the 18 in. double glazed Trombe wall design are assumed to be $9, $13.50, and $18 per ft^2 of glazing when night insulation is excluded; and $12, $18, and $24 per ft^2 of glazing with night insulation included in the design (1,3,5,10).

For the direct gain design (18 in. equivalent storage and double glazing), the costs are $9.50, $12.25, and $19.60 per ft^2 of glazing without inclusion of night insulation; $14, $16.75, and $25 per ft^2 with night insulation included. The $12.25 and $16.75 costs represent a 70/30 mix of south facing to clerestory windows in the direct gain design. The remaining cost figures are for the individual options with south facing windows exhibiting the lower unit cost (Table I).

These national average cost figures were constructed by solar engineers and architects associated with the study. Costs for both designs are adjusted to reflect regional differences in material prices and labor rates by using Mean's (12) 1978 Construction Cost Indices. Total ($) and average ($/10^6 Btu) costs for three representative solar fractions (.20, .40, and .60) for each of the 48 continental states are displayed in Table II for the Trombe wall with night insulation design, and in Table III for the direct gain with night insulation design. The costs are based upon the national average $18 and $16.75 (70/30 mix of south facing and clerestory windows) per ft^2 of glazing for the Trombe wall and direct gain design, respectively.

2.4 Conventional Energy Prices and Futures

Although we have examined many alternative energy futures, only two are used in the economic performance analysis reported here. A 1977 state-by-state energy data base for natural gas ($/MCF) and electricity (¢/Kwh) prices has been constructed previously (5,13,14,15). Two alternative annual escalation rates (in real inflation free terms) are used to project future prices for each state: 4 and 5.5% for natural gas, 0.5 and 2% for electricity. Equivalent delivered heating costs are constructed by transforming these fuel prices, after adjusting for energy conversion efficiencies, into a $/10^6 Btu measure.

3. ECONOMIC OPTIMIZATION AND ANALYSIS

In the actual economic performance evaluation we employ a variant of life cycle cost analysis (1, 3,15,16). Reduced to its simplest form, we evaluate a series of home heating systems that include a solar component providing anywhere from 5 to 95 percent of the required heat to determine the economically optimal mix of solar and conventional back-up systems. The net present value (NPV) of a solar addition (discounted present value of solar system benefits minus solar system costs) over the system life is maximized. This is exactly equivalent to minimizing the cost of delivered heat to the home over a specified life time. Specific values assumed in the economic performance analysis with the LASL/UNM code are as follows: system life = 30 years, real interest = 3.5 percent, inflation rate = 6 percent, nominal interest rate (discount factor) = 9.5 percent, mortgage rate = 9.5 percent, operating and maintenance = 1 percent of system cost, and solar costs and alternative energy costs as discussed above.

4. RESULTS

The results reported here are termed preliminary, because efforts are continuing to refine both the life cycle cost methodology (LASL/UNM economic performance code) and the parameter values employed in that methodology. However, this paper does contain the first presentation of a nationwide (state-by-state) assessment of direct gain solar feasibility. (Trombe wall nationwide feasibility, albeit under differing assumptions about energy futures, has been addressed previously (3,5,10).)

A summary of case descriptions is presented in Table IV. This table serves as the key for interpretation of the information contained in Tables V - VIII which portray the economic performance results (solar fraction only) for both the Trombe wall and direct gain designs with inclusion of the night insulation option. (Although included in our analysis to date, results for both designs without the night insulation option are excluded from the tables. In the following discussion, however, general patterns of solar competitiveness for the Trombe wall and direct gain designs without night insulation are addressed.) For individual design comparisons (differing solar costs and energy futures for each design), equivalent add-on costs are assigned Cases 1 and 4, 2 and 5, 3 and 6. The lower fuel escalation rates are applicable for Cases 1 - 3, the higher rate for Cases 4 - 6.

4.1 Natural Gas Comparison

From inspection of Tables V and VII, several items are noteworthy. First, for both the Trombe wall and direct gain designs the geographical pattern of solar feasibility is generally equivalent as costs are varied. At the higher costs ($24 and $25 per ft² of glazing), solar competitiveness occurs in the New England, Eastern Seaboard, and Pacific Northwest regions. As costs are lowered, states are picked up in the West, North, Midwest, and South; and at the lowest of the three prices ($12 and $14) mid-American states finally join the feasible set. With night insulation the Trombe wall design does slightly better (more states feasible at the higher costs tiers) than direct gain. Optimal solar fractions are equivalent in over half the feasible states--almost all states at the higher cost figures--with the Trombe wall design having the edge in most of the remaining feasible states.

When night insulation is excluded, the Ohio and Mississippi River Valley and Midwest states are the last to achieve solar competitiveness as add-on costs are lowered. Also, the direct gain design now does somewhat better than the Trombe wall design in that more states are feasible at the higher $19.60 and $18/ft² costs. Solar fractions are usually equivalent for both designs.

The year of solar feasibility is usually later than 1978 or 1979 for all states under the two higher add-on cost level and for southern and western states at the lowest cost. The importance of night insulation for the Trombe wall design is apparent throughout the nation. In the majority of states, the percentage increase in performance outweighs the percentage increase in cost due to night insulation. However, for direct gain, this seemingly universal trend does not hold. Adding night insulation improves economic performance in the northern tier. The performance increase outweighs the cost increase in the north, while the opposite holds in the south. Curiously enough, in the southern tier of states, direct gain without night insulation economically outperforms the Trombe wall with night insulation. In the northern latitudes, the Trombe wall with night insulation outperforms the direct gain design with night insulation. So it appears that Trombe wall with night insulation is best for the north and direct gain without night insulation best for the south. This is a preliminary result, but quite interesting. As a final note, both designs compete much more favorably when the real natural gas escalation rate is raised from 4% to 5.5%. Because the initial price levels of gas are relatively low, this 1.5% increase has a substantial incremental effect on the annualized cost of natural gas, and hence upon the solar economics.

4.2 Electric Resistance Comparison

When electric resistance is contrasted against the Trombe wall and direct gain design (Table VI and VIII), solar add-on costs are not nearly so critical as against natural gas. Except for states in the lower Mississippi Valley, Ohio River Valley, and Pacific Northwest regions either design achieves solar competitives in 1978 (at the 0.5% escalation rate) across the U. S. at the highest cost ($24 and $25/ft² of glazing). Without inclusion of night insulation, this geographical pattern for cost comparisons moves into the midwest for direct gain, Central Plains states for Trombe wall.

Optimal solar fractions are generally higher for the direct gain design (except in the northern tier states) than with the Trombe wall design at the two higher cost levels. At the lower cost level the solar fractions are usually equivalent, with both designs at their physical sizing limit in many of the northern tier states.

Contrary to the natural gas case, against electric resistance both the Trombe wall and direct gain designs do better with night insulation than without at the optimal system sizes. In the case of direct gain this would indicate that night insulation becomes relatively more important as system size and night time losses on a per square foot basis increase.

5. ACKNOWLEDGEMENTS

The authors wish to thank Bill Wray, Bob McFarland, and Doug Balcomb for providing us with the solar performance data.

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TABLE I

DETAILED COST+ BREAKDOWN FOR DIRECT GAIN

($/ft^2 of Glazing)

South Facing Window	Cost‡	Clerestory Window	Cost‡
Glazing--Glass (Tempered) double 2 93/16"	3.54	Glazing--Glass (Non-tempered) double 2 93/16"	2.35
Framing -- 4' X 8' = 24ft$_L$	2.86	Framing -- 4' X 10' = 28ft$_L$	2.70
Header Trim or Overhang	1.36	Roof Structure	4.95
Concrete Slab -- 2" additional	1.74	Concrete Block 8"	8.15
Concrete Block -- 8"	3.37	Footing -- 8" foundation	1.45
Interior Wall Credit	(1.10)	No Wall Credits§	--
Exterior Wall Credit	(2.27)		
Total System	9.50	Total System	19.60
Night Insulation (R-9)	4.50	Night Insulation (R-9)	5.40

+Dollar Costs are for National averages.

‡Includes both materials and labor.

§See text for explanation.

TABLE II

TOTAL ($) AND AVERAGE* ($/10^6 BTU) COST FOR

REPRESENTATIVE SOLAR FRACTIONS

TROMBE WALL WITH NIGHT INSULATION‡

State	.20 TC	.20 AC	.40 TC	.40 AC	.60 TC	.60 AC
Alabama	1260	14.25	3035	15.21	5609	19.59
Arizona	364	15.13	1895	16.63	3302	19.34
Arkansas	1719	15.37	3886	19.73	--	--
California	305	12.12	1923	13.72	3221	16.16
Colorado	2361	13.26	5194	14.53	--	--
Connecticut	2588	13.63	6003	15.31	--	--
Delaware	2643	19.41	6073	22.30	--	--
Florida	171	24.81	358	25.95	606	29.28
Georgia	1502	15.74	3419	17.91	6196	21.54
Idaho	2318	12.38	5527	14.92	--	--
Illinois	3417	17.22	8054	20.30	--	--
Indiana	2985	16.25	7098	19.32	--	--
Iowa	3238	15.25	7740	18.22	--	--
Kansas	2569	15.38	5947	17.30	--	--
Kentucky	2864	13.37	5683	22.13	--	--
Louisiana	1442	20.48	3229	22.33	5225	27.58
Maine	2932	11.70	6564	13.56	--	--
Maryland	2174	15.36	5037	18.50	--	--
Massachusetts	3229	17.77	7417	20.42	--	--
Michigan	3970	17.83	--	--	--	--
Minnesota	3902	14.44	--	--	--	--
Mississippi	1409	20.31	3140	22.30	5495	25.02
Missouri	2903	17.24	6575	20.21	--	--
Montana	2959	11.34	5905	13.32	--	--
Nebraska	2940	13.79	6818	15.39	--	--
Nevada	1249	14.31	2816	16.12	4997	19.07
New Hampshire	3791	14.22	--	--	--	--
New Jersey	2963	19.10	6875	22.15	--	--
New Mexico	1635	11.67	3629	12.34	6441	15.32
New York	3468	22.08	8067	25.59	--	--
North Carolina	1480	13.53	3363	15.37	6022	18.25
North Dakota	3298	11.53	--	--	--	--
Ohio	4156	20.30	--	--	--	--
Oklahoma	1837	15.30	4157	17.31	7348	20.40
Oregon	2337	15.34	5675	18.53	--	--
Pennsylvania	3785	19.79	3535	23.41	--	--
Rhode Island	2730	14.36	6323	16.90	--	--
South Carolina	920	14.03	2069	15.79	3673	18.38
South Dakota	2605	11.30	6045	12.76	--	--
Tennessee	1868	16.20	4387	19.02	--	--
Texas	1200	16.77	2878	18.56	5095	21.31
Utah	2275	12.17	5541	14.20	--	--
Vermont	4152	15.38	--	--	--	--
Virginia	2027	14.39	4594	16.37	--	--
Washington	2409	15.39	6083	21.33	--	--
West Virginia	3389	20.13	7989	23.73	--	--
Wisconsin	3401	13.42	--	--	--	--
Wyoming	2815	11.33	6244	13.12	--	--

TC = Total Cost AC = Average Cost

-- The particular design configuration evaluated here cannot supply sufficient heat to meet this fraction (physical construction limitations).

*See Roach, etal. (1979) for derivation of average cost formulation. Parameter Values Assumed: real rate of interest = .035, inflation rate = .06, mortgage rate = .095, operating and maintenance = .01•(system cost), and system life = 30 years.

‡National dollar cost of $18/ft^2 of glazing is adjusted regionally by using Means (1978).

TABLE III

TOTAL ($) AND AVERAGE* ($/10^6 BTU) COST FOR

REPRESENTATIVE SOLAR FRACTIONS

DIRECT GAIN WITH NIGHT INSULATION‡

State	.20 TC	.20 AC	.40 TC	.40 AC	.60 TC	.60 AC
Alabama	683	9.54	1571	10.37	2708	12.61
Arizona	429	10.06	931	10.91	1569	12.25
Arkansas	878	11.25	2019	12.97	3521	15.08
California	187	7.77	382	8.36	1493	9.39
Colorado	2317	17.35	5050	13.31	--	--
Connecticut	1550	10.38	3648	12.31	--	--
Delaware	1247	12.21	2835	14.13	5178	16.90
Florida	81	15.72	170	16.46	277	17.33
Georgia	754	10.54	1735	12.12	2991	13.93
Idaho	1209	8.61	2944	10.48	5887	13.97
Illinois	1897	12.75	4589	15.42	--	--
Indiana	1520	11.78	3964	14.39	--	--
Iowa	1833	11.51	4407	13.34	--	--
Kansas	1388	11.08	3286	13.12	5854	15.57
Kentucky	1572	13.39	3742	15.53	--	--
Louisiana	651	12.34	1444	13.68	2441	15.41
Maine	1560	8.59	3744	10.31	--	--
Maryland	1143	11.19	2544	12.35	4747	15.49
Massachusetts	1300	13.21	4236	15.55	--	--
Michigan	2220	13.29	5522	16.53	--	--
Minnesota	2224	10.38	5592	13.30	--	--
Mississippi	723	13.59	1603	15.18	2709	17.10
Missouri	1496	12.25	3576	14.55	6592	18.01
Montana	1638	8.74	3945	10.53	--	--
Nebraska	1316	8.23	3168	9.91	5664	11.31
Nevada	621	9.49	1398	10.68	2406	12.25
New Hampshire	2365	11.33	--	--	--	--
New Jersey	1635	14.05	3865	16.61	--	--
New Mexico	337	7.36	1841	8.73	3174	10.07
New York	1875	15.92	4434	13.33	--	--
North Carolina	755	9.21	1736	10.58	2962	12.04
North Dakota	1859	8.69	4745	11.09	--	--
Ohio	2452	15.97	6346	20.57	--	--
Oklahoma	960	10.66	2194	12.18	3840	14.21
Oregon	1213	10.61	2937	12.35	5793	15.90
Pennsylvania	2100	14.54	5099	17.77	--	--
Rhode Island	1542	10.39	3518	12.39	--	--
South Carolina	455	9.25	1025	10.43	1720	11.57
South Dakota	1422	8.01	3326	9.37	--	--
Tennessee	982	11.35	2346	13.36	4222	16.27
Texas	648	11.14	1428	12.28	2417	13.86
Utah	1243	8.50	2938	10.04	5387	12.27
Vermont	2591	12.96	--	--	--	--
Virginia	1059	10.37	2450	12.00	4397	14.35
Washington	1254	11.72	3221	15.06	--	--
West Virginia	1900	15.08	4660	18.30	--	--
Wisconsin	1962	10.32	4933	12.37	--	--
Wyoming	1541	8.64	3454	9.68	6071	11.34

TC = Total Cost AC = Average Cost

-- The particular design configuration evaluated here cannot supply enough heat to meet this fraction (physical construction limitations).

*See Roach, et al (1979) for derivation of average cost formulation. Parameter values assumed: real rate of interest = .035, inflation rate = .06, mortgage rate = .095, operating and maintenance = .01 (system cost), and system life = 30 years.

‡National dollar cost of $14/ft^2 of glazing is adjusted regionally by using Means (1979). The $14/ft^2 of glazing assumes only south facing windows. For the .70/.30 split (south facing window to clerestory window ratio) used in the analysis, the above $values should be multiplied by 1.20. For an all clerestory cost the above values should be multiplied by 1.3.

TABLE IV

DESCRIPTION OF THE CASES*

CASE NUMBER	FUEL ESCALATION RATES‡ (PERCENT)	TROMBE WALL WITHOUT NIGHT INSULATION ($/ft^2)	TROMBE WALL WITH NIGHT INSULATION ($/ft^2)	DIRECT GAINS WITHOUT NIGHT INSULATION ($/ft^2)	DIRECT GAINS WITH NIGHT INSULATION ($/ft^2)
1	1	9.00	12.00	9.50	14.00
2	1	13.50	18.00	12.25	16.75
3	1	18.00	24.00	19.60	25.00
4	2	9.00	12.00	9.50	14.00
5	2	13.50	18.00	12.25	16.75
6	2	18.00	24.00	19.60	25.00

*The Trombe wall and direct gain design <u>without</u> the night insulation option are excluded from discussion of results in this paper (Tables V - VIII).

‡Fuel Escalation Rate (percent)

Fuel	2	1
Natural Gas	5.5	4.0
Heating Oil	4.0	2.0
Electricity	2.0	0.5

§These dollar costs assume (1) all south facing windows - Cases 1 and 4, (2) .70 south facing windows and .30 clerestory windows - Cases 2 and 5, (3) all clerestory windows - Cases 3 and 6.

TABLE V

SUMMARY OF RESULTS FOR TROMBE WALL WITH NIGHT INSULATION

ALTERNATIVE FUEL - NATURAL GAS

SOLAR FRACTION*

STATE	CASES‡ 1	2	3	4	5	6
Alabama	25	20	0	45	20	20
Arizona	30	20	0	30	20	20
Arkansas	20	0	0	20	20	0
California	20	20	0	45	20	20
Colorado	20	0	0	25	20	0
Connecticut	45	20	20	45	40	20
Delaware	20	0	0	30	20	20
Florida	20	0	0	20	25	0
Georgia	20	0	0	20	20	0
Idaho	45	30	20	45	40	30
Illinois	20	0	0	30	20	20
Indiana	20	0	0	25	20	20
Iowa	20	0	0	25	20	20
Kansas	20	0	0	20	20	0
Kentucky	20	20	0	35	20	20
Louisiana	0	0	0	20	0	0
Maine	40	40	40	40	40	40
Maryland	35	20	20	50	25	20
Massachusetts	40	20	20	40	25	20
Michigan	20	20	0	35	20	20
Minnesota	25	20	0	35	20	20
Mississippi	20	0	0	20	20	0
Missouri	20	0	0	20	20	0
Montana	30	20	0	40	20	20
Nebraska	20	0	0	25	20	20
Nevada	20	20	0	40	20	20
New Hampshire	30	25	20	30	30	25
New Jersey	35	20	20	45	25	20
New Mexico	25	20	0	45	20	25
New York	20	20	0	40	20	20
North Carolina	45	20	20	50	30	20
North Dakota	20	20	0	35	20	20
Ohio	20	0	0	20	20	0
Oklahoma	0	0	0	20	0	0
Oregon	35	20	20	50	25	20
Pennsylvania	20	20	0	35	20	20
Rhode Island	45	40	20	45	45	30
South Carolina	20	20	0	40	20	20
South Dakota	25	20	0	40	20	20
Tennessee	20	0	0	20	20	20
Texas	25	20	0	45	20	20
Utah	20	0	0	25	20	0
Vermont	30	25	20	30	30	25
Virginia	45	20	20	55	35	20
Washington	25	20	0	35	20	20
West Virginia	20	0	0	25	20	20
Wisconsin	35	20	20	35	25	20
Wyoming	35	20	0	50	20	20

0 --indicates no feasibility.

*Expressed in percentage terms

‡See Table IV and main text for a description of the cases.

TABLE VI

SUMMARY OF RESULTS FOR TROMBE WALL WITH NIGHT INSULATION

ALTERNATIVE FUEL - ELECTRICITY (RESISTANCE)

SOLAR FRACTION*

STATE	CASES‡ 1	2	3	4	5	6
Alabama	65	45	30	55	50	45
Arizona	75	55	50	30	70	50
Arkansas	55	30	0	55	45	20
California	75	50	50	30	70	50
Colorado	55	55	40	55	55	45
Connecticut	45	45	45	45	45	45
Delaware	50	45	25	50	50	45
Florida	60	35	0	70	55	25
Georgia	65	50	30	65	60	45
Idaho	45	30	0	45	40	25
Illinois	40	35	20	40	40	30
Indiana	40	40	20	40	40	35
Iowa	40	40	25	40	40	40
Kansas	45	45	20	45	45	35
Kentucky	45	20	0	45	30	20
Louisiana	45	0	0	55	35	20
Maine	40	40	40	40	40	40
Maryland	50	50	35	50	50	50
Massachusetts	40	40	40	40	40	40
Michigan	35	35	20	35	35	30
Minnesota	35	35	35	35	35	35
Mississippi	60	40	0	70	55	35
Missouri	50	35	20	50	50	35
Montana	40	40	20	40	40	30
Nebraska	40	40	35	40	40	40
Nevada	65	50	25	70	50	45
New Hampshire	30	30	30	30	30	30
New Jersey	45	45	35	45	45	45
New Mexico	65	50	50	65	55	60
New York	45	45	40	45	45	45
North Carolina	60	60	0	60	50	55
North Dakota	35	35	35	35	35	35
Ohio	35	30	0	35	35	25
Oklahoma	50	40	20	50	55	40
Oregon	40	20	0	50	30	20
Pennsylvania	40	35	20	40	40	35
Rhode Island	45	45	45	45	45	45
South Carolina	75	60	45	75	55	55
South Dakota	45	45	45	45	45	45
Tennessee	45	20	0	55	40	20
Texas	65	45	20	70	55	40
Utah	50	45	30	50	50	45
Vermont	30	30	30	30	30	30
Virginia	55	55	50	55	55	55
Washington	0	0	0	20	0	0
West Virginia	40	30	0	40	40	25
Wisconsin	35	35	30	35	35	35
Wyoming	50	45	20	50	50	45

0 --indicates no feasibility.

*Expressed in percentage terms

‡See Table IV and main text for a description of the cases.

TABLE VII

SUMMARY OF RESULTS FOR DIRECT GAIN WITH NIGHT INSULATION

ALTERNATIVE FUEL - NATURAL GAS

SOLAR FRACTION*

STATE	CASES‡ 1	2	3	4	5	6
Alabama	25	20	0	45	30	20
Arizona	30	20	0	55	40	20
Arkansas	20	0	0	20	20	20
California	25	20	0	45	30	20
Colorado	0	0	0	25	0	0
Connecticut	35	20	20	50	40	20
Delaware	20	20	0	30	20	20
Florida	25	25	0	20	30	25
Georgia	20	20	0	20	20	20
Idaho	45	40	20	55	50	30
Illinois	20	20	0	20	20	20
Indiana	20	20	0	20	20	20
Iowa	20	20	0	20	20	20
Kansas	0	0	0	20	20	0
Kentucky	20	20	0	25	20	20
Louisana	0	0	0	20	20	0
Maine	50	50	40	50	50	50
Maryland	35	20	20	55	40	20
Massachusetts	25	20	20	45	35	20
Michigan	20	20	0	25	20	20
Minnesota	20	20	0	25	20	20
Mississippi	20	0	0	20	20	0
Missouri	20	0	0	20	20	20
Montana	20	20	0	35	25	20
Nebraska	20	20	0	30	20	20
Nevada	20	20	0	40	20	20
New Hampshire	30	25	20	35	35	20
New Jersey	25	20	20	40	35	20
New Mexico	20	20	0	45	30	20
New York	20	20	0	35	20	20
North Carolina	45	30	20	60	55	20
North Dakota	20	20	0	25	20	20
Ohio	0	0	0	20	20	0
Oklahoma	0	0	0	20	20	0
Oregon	35	20	20	45	35	20
Pennsylvania	20	20	0	25	20	20
Rhode Island	55	40	20	55	55	35
South Carolina	20	20	0	45	20	20
South Dakota	20	20	0	35	20	20
Tennessee	20	20	0	20	20	20
Texas	25	20	0	30	30	25
Utah	20	20	0	25	20	20
Vermont	30	20	20	35	35	20
Virginia	40	25	20	55	45	20
Washington	20	20	20	35	25	20
West Virginia	20	0	0	20	20	20
Wisconsin	20	20	0	35	25	20
Wyoming	25	20	0	55	35	20

0 —Indicates no feasibility.

*Expressed in percentage terms

‡See Table IV and main text for a description of the cases.

TABLE VIII

SUMMARY OF RESULTS FOR DIRECT GAIN WITH NIGHT INSULATION

ALTERNATIVE FUEL - ELECTRICITY (RESISTANCE)

SOLAR FRACTION*

STATE	CASES‡ 1	2	3	4	5	6
Alabama	55	55	40	70	65	55
Arizona	75	75	60	80	80	70
Arkansas	55	45	0	65	55	25
California	80	75	60	65	80	70
Colorado	40	25	0	45	40	25
Connecticut	50	50	45	50	50	50
Delaware	65	50	40	65	55	55
Florida	55	60	25	75	70	50
Georgia	65	65	40	70	65	50
Idaho	45	40	20	55	50	30
Illinois	45	35	20	50	45	25
Indiana	50	45	20	50	50	35
Iowa	45	45	25	45	45	40
Kansas	50	50	25	50	50	35
Kentucky	35	25	0	45	35	20
Louisiana	55	45	0	55	50	25
Maine	50	50	40	50	50	50
Maryland	55	60	45	55	55	55
Massachusetts	50	50	30	50	50	50
Michigan	45	35	0	45	45	25
Minnesota	40	40	30	40	40	40
Mississippi	65	55	20	70	55	45
Missouri	50	40	20	50	50	35
Montana	45	40	20	50	50	30
Nebraska	60	50	40	50	50	55
Nevada	70	65	40	75	70	55
New Hampshire	35	35	30	35	35	35
New Jersey	55	55	35	55	55	50
New Mexico	75	70	55	80	75	65
New York	55	55	40	55	55	50
North Carolina	70	65	55	75	70	60
North Dakota	45	45	35	45	45	45
Ohio	40	25	0	40	40	20
Oklahoma	60	55	25	70	55	50
Oregon	35	30	0	45	40	20
Pennsylvania	45	35	20	45	45	30
Rhode Island	55	55	40	55	55	55
South Carolina	75	75	60	80	75	55
South Dakota	55	55	55	55	55	55
Tennessee	50	30	0	55	50	20
Texas	70	65	30	70	70	50
Utah	65	55	30	65	65	45
Vermont	35	35	25	35	35	35
Virginia	55	65	50	65	55	50
Washington	0	0	0	20	20	0
West Virginia	40	35	0	45	40	25
Wisconsin	45	45	25	45	45	40
Wyoming	50	55	20	60	60	45

0 --Indicates no feasibility.

*Expressed in percentage terms

‡See Table IV and main text for a description of the cases.